



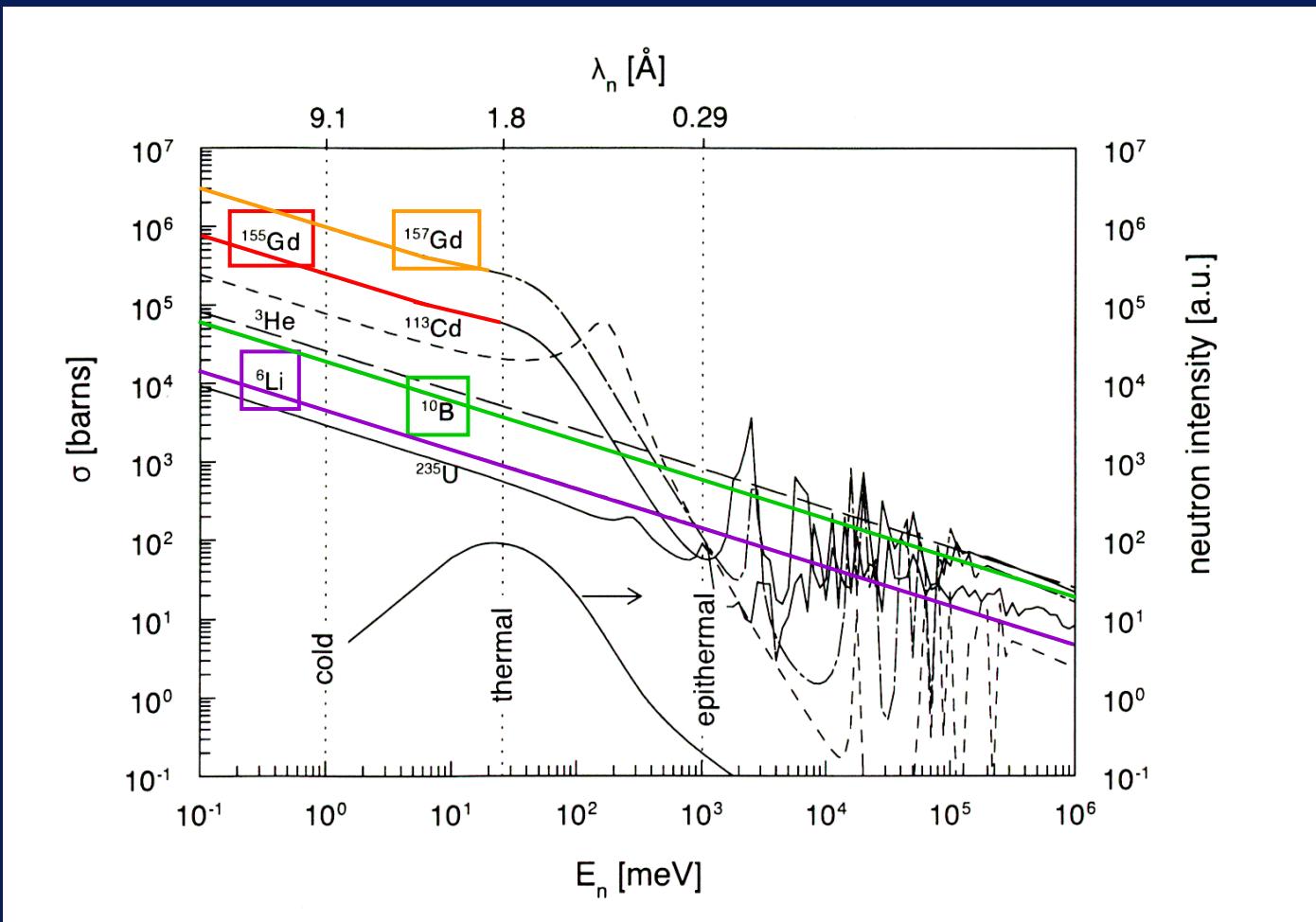
Inorganic scintillators for neutron detection

C.W.E. van Eijk

29th & 30th May 2003
Indiana Univ., Bloomington

Inorganic Neutron Scintillators

some neutron-capture cross sections



Inorganic Neutron Scintillators

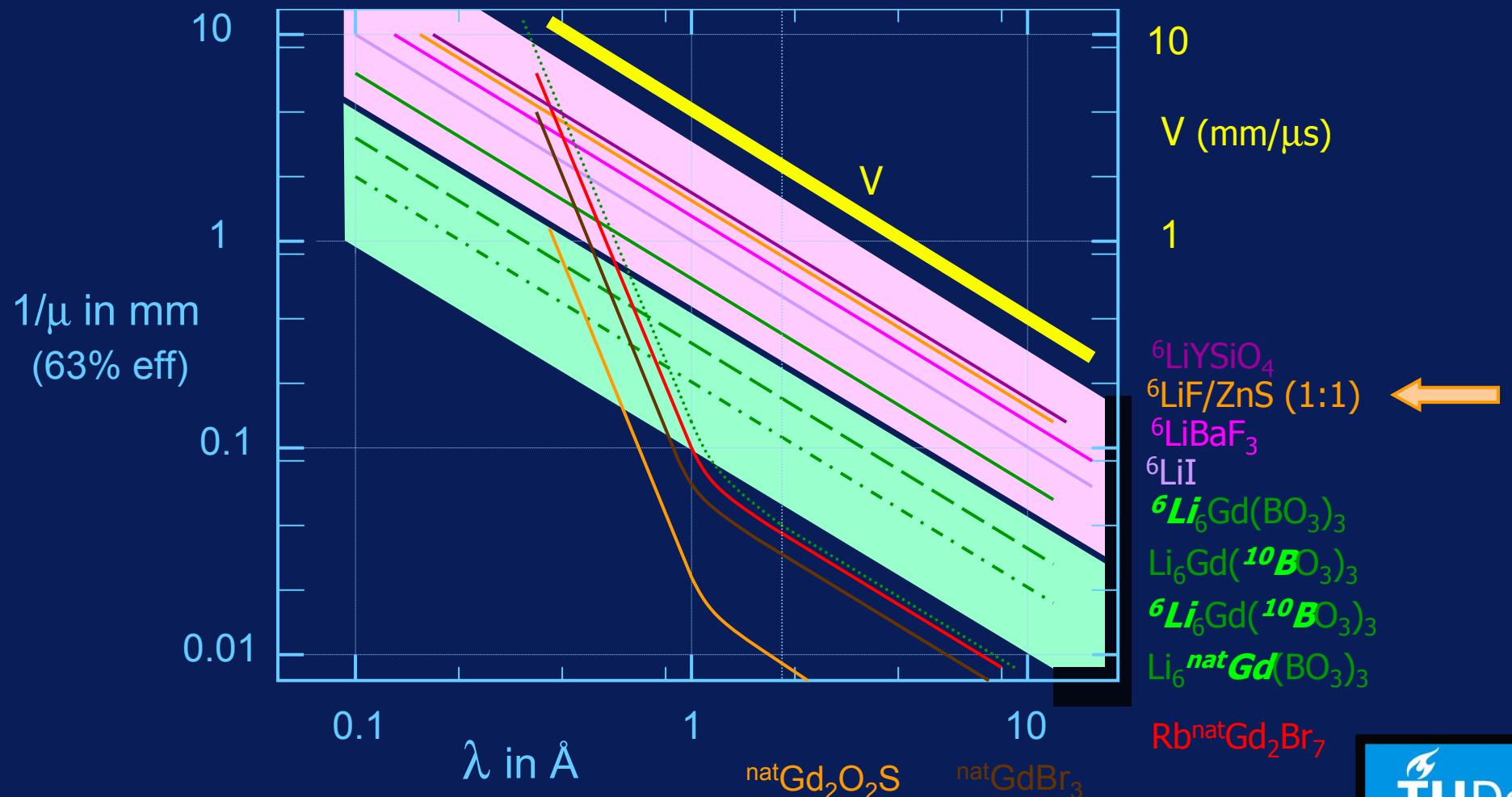
Li, B and Gd containing thermal-neutron scintillators

	Scintill. host	Dopant/ conc-mol%	λ_{em} nm	Light yield		τ ns	Density ρ g/cm ³	ρZ_{eff}^4 (x 10 ⁻⁶) ‡
				photons per neutron	MeV gamma			
★	⁶ Li-glass	Ce	395	~6,000	~4,000	75	2.5	
★	⁶ Lil	Eu	470	50,000	12,000	1.4*10 ³	4.1	31
★	⁶ LiF/ZnS	Ag	450	160,000	~75,000	~1*10 ³	2.6	1.2
	LiBaF ₃	-	190- 290	1,700	3,000	1/13μs	5.3	35
	LiBaF ₃	Ce/0.3, K/1	190- 330	3,500	5,000	1/34/2.1μs	5.3	35
	LiBaF ₃	Ce/0.3, Rb/1	190- 330	3,600	4,500	1/34/2.4μs	5.3	35
★	LiYSiO ₄	Ce/5	410	10,000	10,000	38	3.8	4
	Li ₆ Y(BO ₃) ₃	Ce/~1	390,420	8,000	~2,000		2.8	
★	⁶ Li ₆ Gd(BO ₃) ₃	Ce/1-4	385,415	40,000	14,000	200/800	3.5	25
	Li ₆ Lu(BO ₃) ₃	Ce/~1	~400		~4,000			
★	Cs ₂ LiYCl ₆	Ce/0.1	380		33,000			
★	RbGd ₂ Br ₇	Ce/10	420	~5,000	54,000	43/400	4.8	31
	GdBr ₃	Ce/2	420,450	~4,500	47,000	14/82/700	4.6	34
	Gd ₂ SiO ₅	Ce/0.5	440	800	9,000	60	6.7	84
★	Gd ₂ O ₂ S	Pr/Ce/F	510	~3,000	40,000	~ μs	7.3	101

‡As an indication of gamma- ray detection efficiency by photoelectric effect ρZ_{eff}^4 values are presented

Inorganic Neutron Scintillators

neutron scintillator absorption length



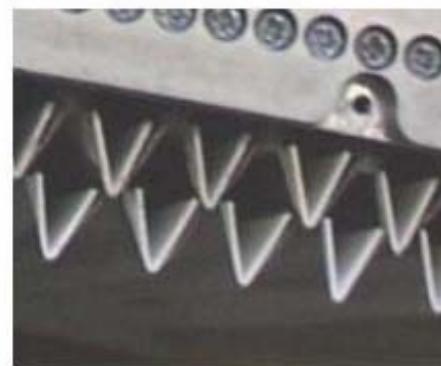
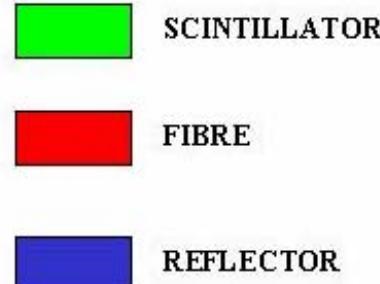
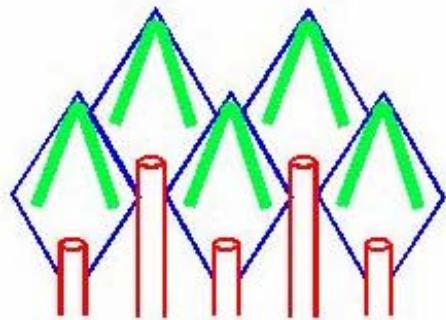
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GEM detector ISIS

$^6\text{LiF}/\text{ZnS:Ag}$

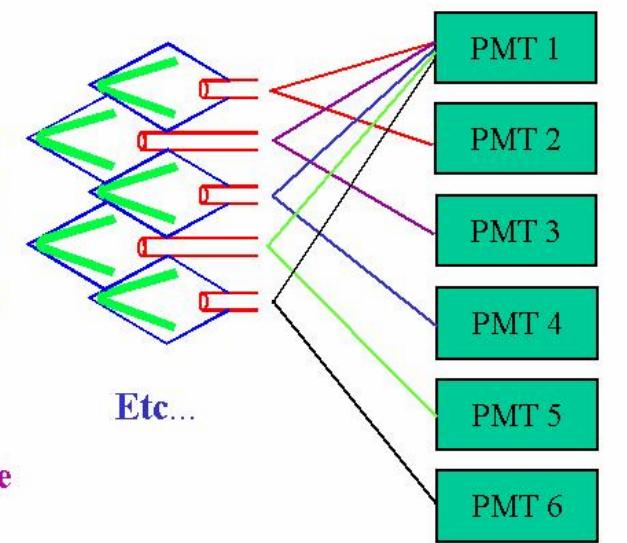
V shaped

5 mm resolution - two layers



Code 1,2 Ele 1
Code 1,3 Ele 2
Code 1,4 Ele 3
Code 1,5 Ele 4
Code 1,6 Ele 5

The $^2\text{C}_n$ Code



$^6\text{LiF}/\text{ZnS:Ag}$
opaque
effective ~ 0.5 mm

From: Rhodes, ISIS-RAL, PSND Workshop Berlin, June 28-30, 2001

Inorganic Neutron Scintillators

ENGIN-X detector ISIS

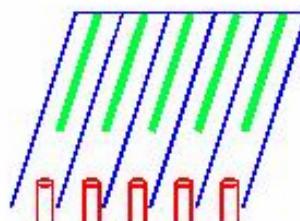
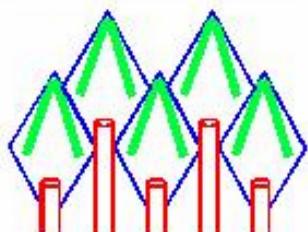
V DETECTOR



VENETIAN DETECTOR



${}^6\text{LiF}/\text{ZnS}:{}\text{Ag}$



From: Rhodes, ISIS-RAL, PSND Workshop Berlin, June 28-30, 2001

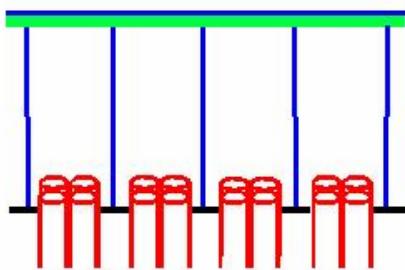
Inorganic Neutron Scintillators

SXD detector ISIS

${}^6\text{LiF}/\text{ZnS}:{}\text{Ag}$
also ${}^6\text{Li}_6{}^{158}\text{Gd}(\text{BO}_3)_3:\text{Ce}^{3+}$

The 2D position sensitive scintillation detectors

Three detectors operational prior to upgrade
In house manufacture



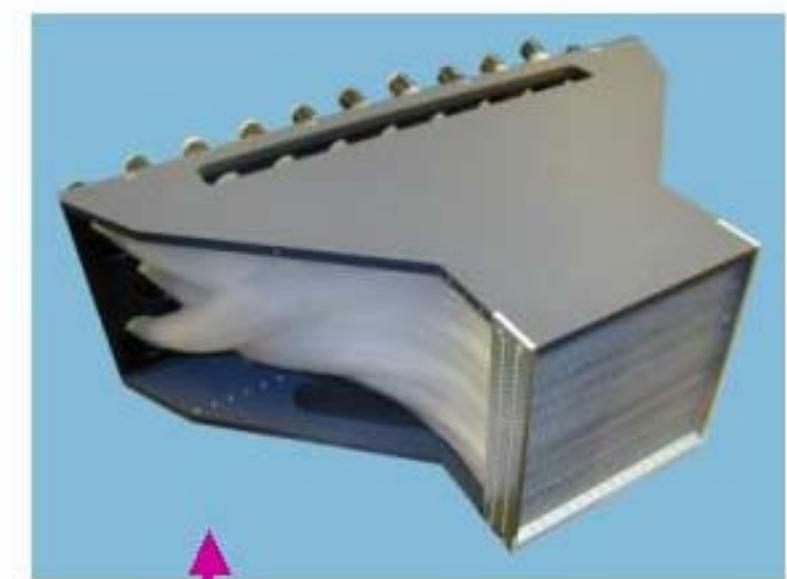
SCINTILLATOR
FIBRE
REFLECTOR

QUAD
COINCIDENT
CODE

196 x 196 mm detector

3 x 3 mm resln.

4096 elements



The coded fibre optic array

From: Rhodes, ISIS-RAL, PSND Workshop Berlin, June 28-30, 2001

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ISIS detector characteristics

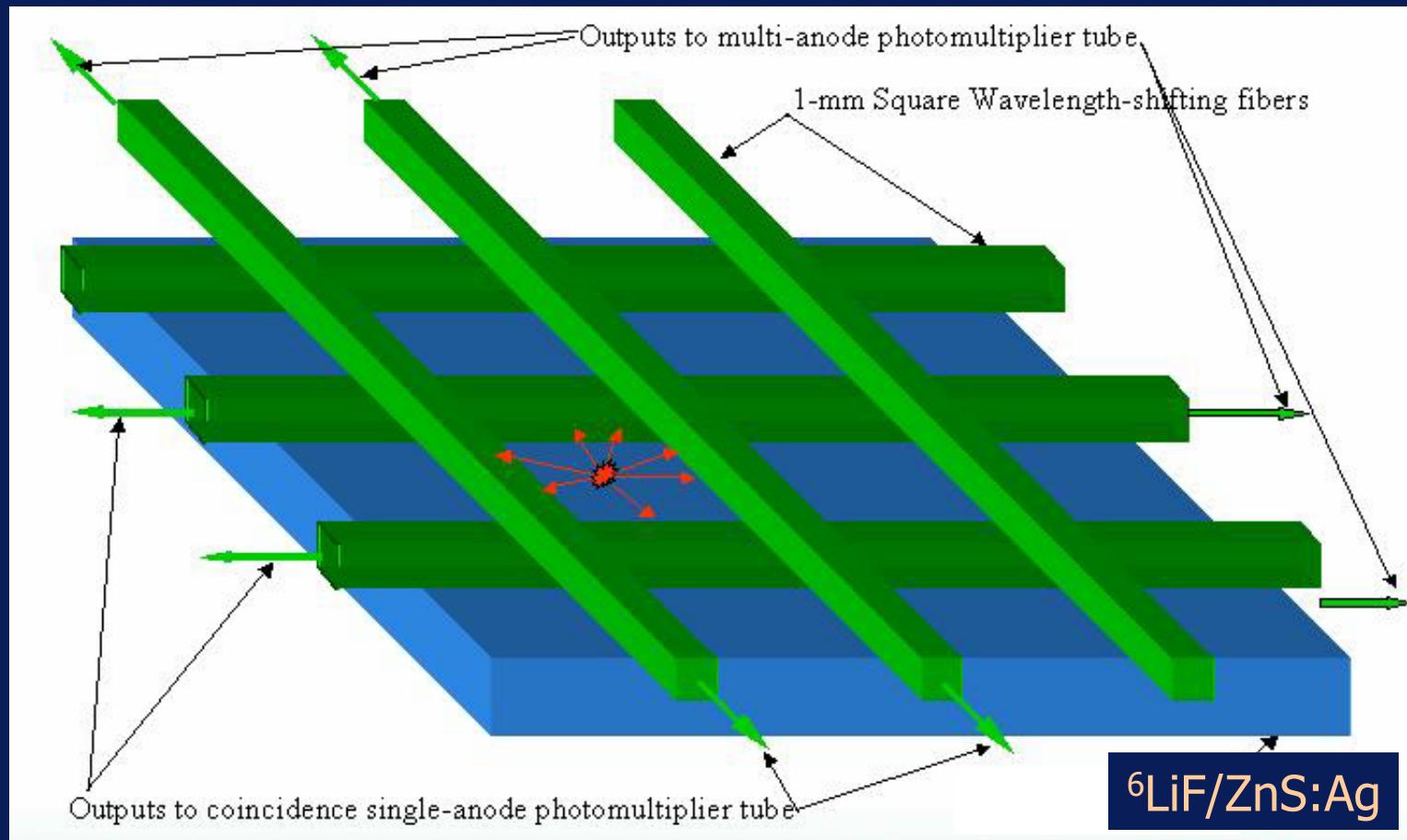
$^6\text{LiF}/\text{ZnS}:Ag$

	GEM	SXD
Detector Efficiency (1 Å)	50%	20% - single screen
Gamma Efficiency (^{60}Co)	10^{-7}	10^{-8}
Intrinsic background	12 c /element /hr	0.006 c / element / hr
Spatial Resolution	5 mm	3 mm x 3 mm
Pulse pair resolution	2.5 μs	2.5 μs
Stability	< 0.1 % / $^{\circ}\text{C}$	est. 0.1 % / $^{\circ}\text{C}$
Parallax		minimal ($t_{\text{active}} = 0.4 \text{ mm}$)

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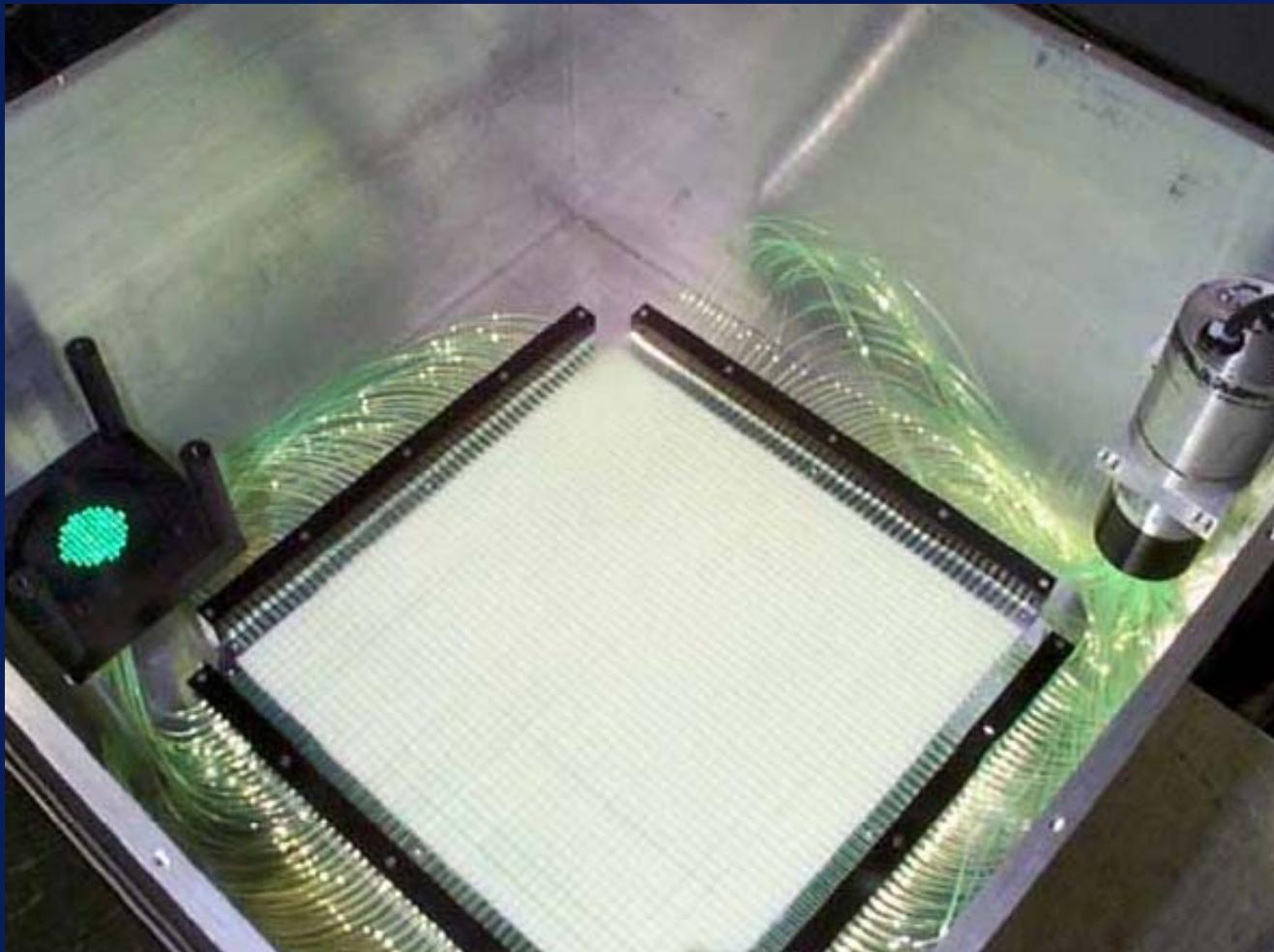
Crossed fibre PSD

ORNL



From: Hutchinson et al, ORNL, PSND Workshop Berlin, June 28-30, 2001

Inorganic Neutron Scintillators



Analogous concepts

- ORNL
- IHEP, JINR, Moscow
- RIKEN, KEK, Waseda Univ,
- JAERI, Tokyo Inst. Techn.
- ILL, CERN, Soreq NRC

$^6\text{LiF}/\text{ZnS}:Ag$

Pos. resol. 0.5 - 5 mm

Eff 18% @ 2.5 Å

up to 50 x 50 cm²

Eff 45% for 3 screens

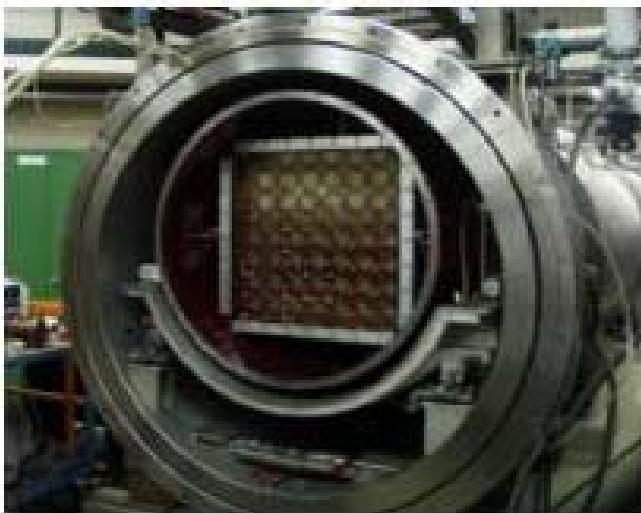
GS20 glass

Eff 80% @ 2.5 Å

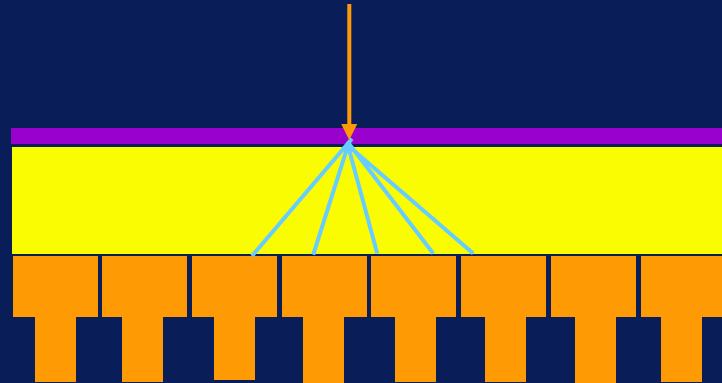
From: Hutchinson et al, ORNL, PSND Workshop Berlin, June 28-30, 2001

Inorganic Neutron Scintillators

FZ Juelich



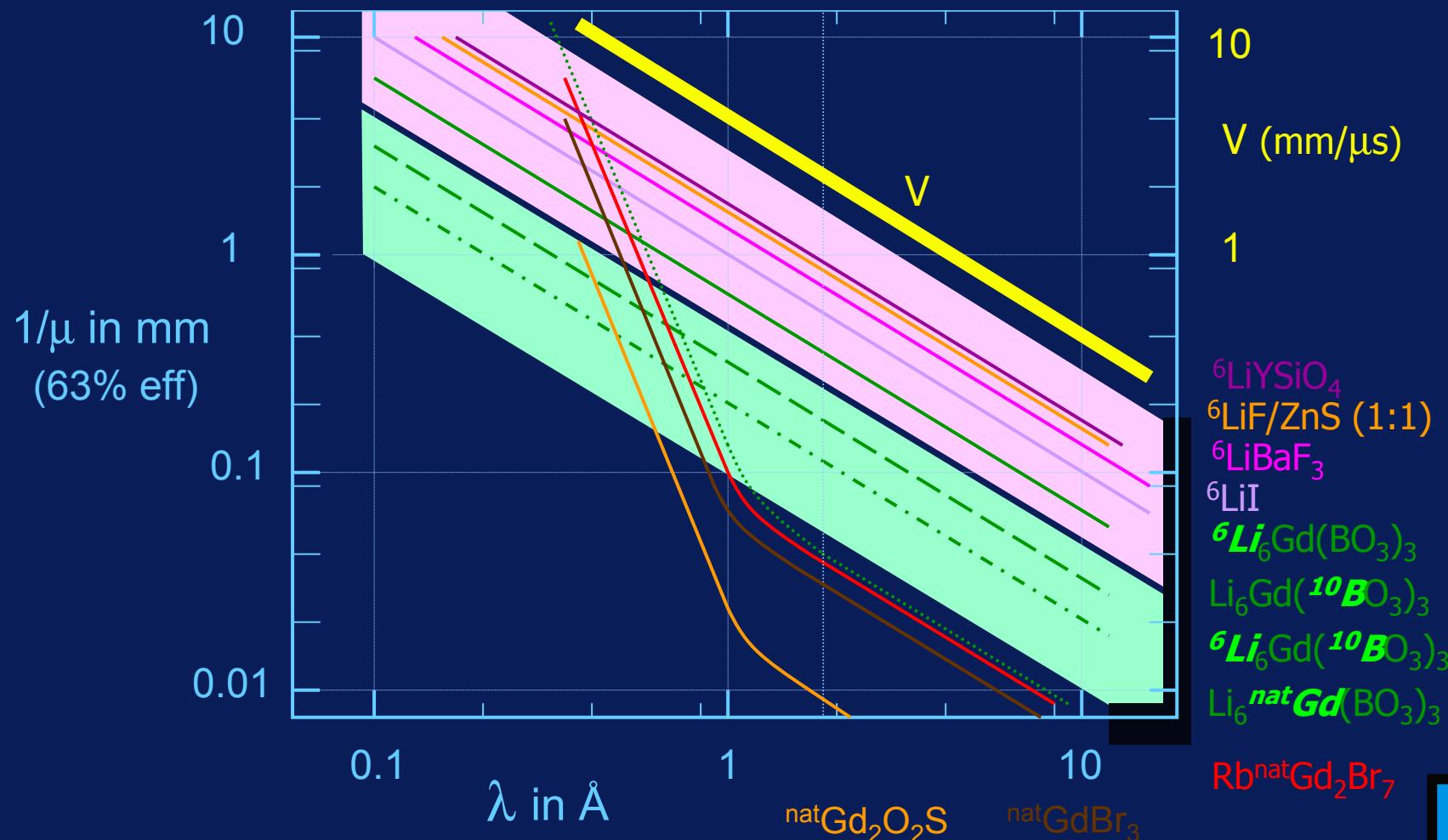
Anger camera
readout per PMT
1 mm GS20 ^{6}Li glass



Detection efficiency 85% at 2 Å
spatial resolution 3 mm
area $60 \times 60 \text{ cm}^2$
dead time 1 μs

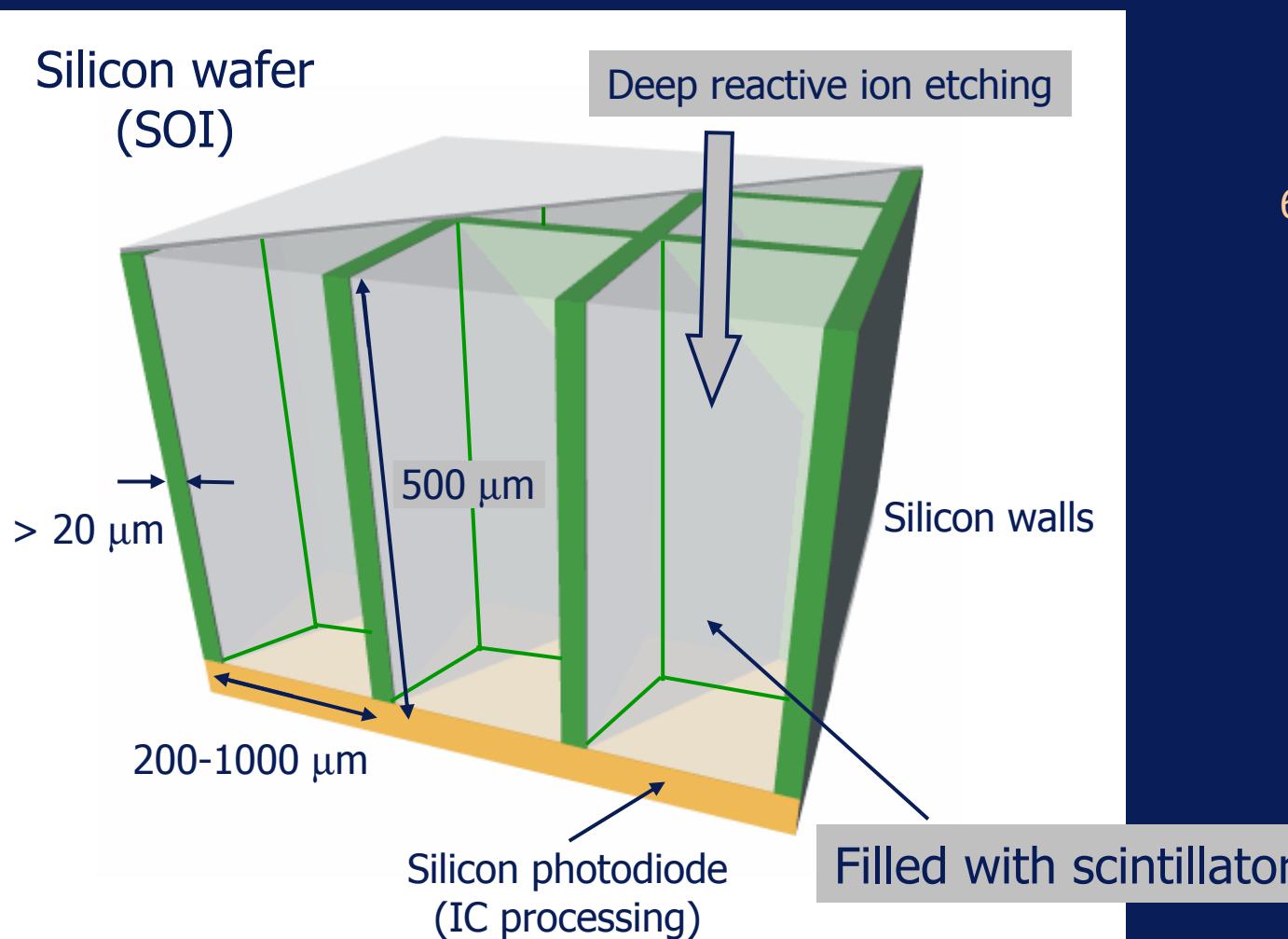
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neutron scintillator absorption length



Inorganic Neutron Scintillators

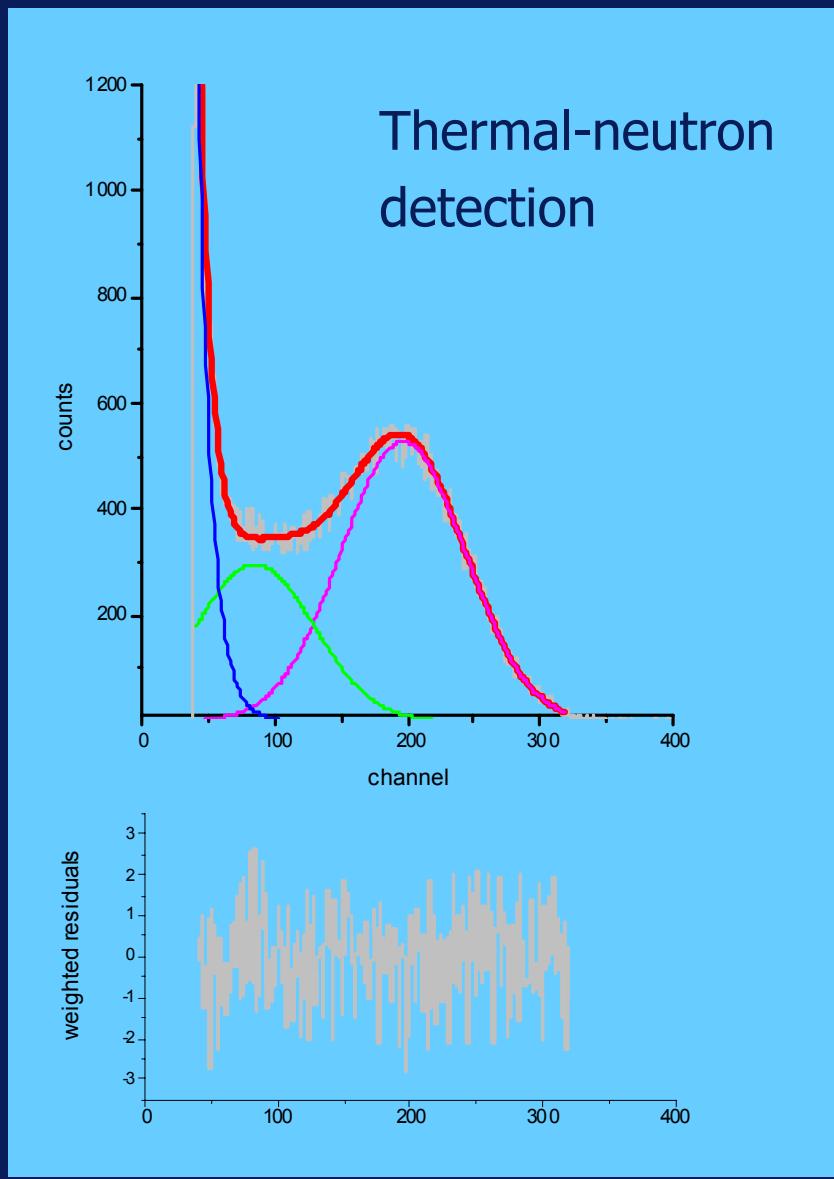
Silicon-well-scintillator detector



${}^6\text{Li}_6{}^{158}\text{Gd}(\text{BO}_3)_3:\text{Ce}^{3+}$
+
wavelength shifter
(600 nm)

TU Delft, Photogenics

Inorganic Neutron Scintillators



Silicon-well-scintillator detector



+

wavelength shifter
(600 nm)

TU Delft, Photogenics

Inorganic Neutron Scintillators



Silicon-well-scintillator detector

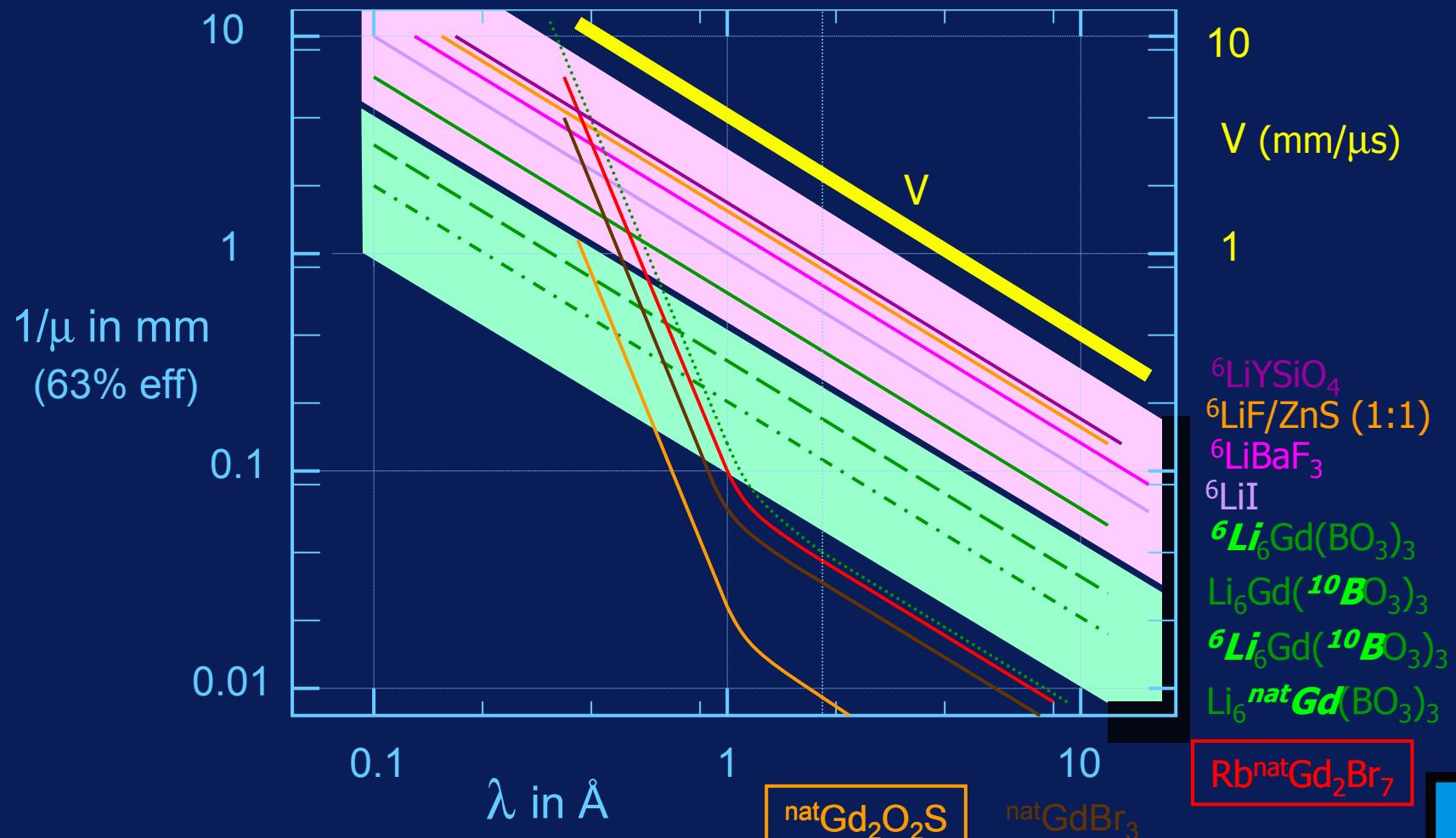
TU Delft, Photogenics

Develop:

- thin walls
- reflectivity of walls
- optimized diode in bottom
- diode window (light detection efficiency)
- scintillator loading
- readout scheme

Inorganic Neutron Scintillators

neutron scintillator absorption length



Inorganic Neutron Scintillators

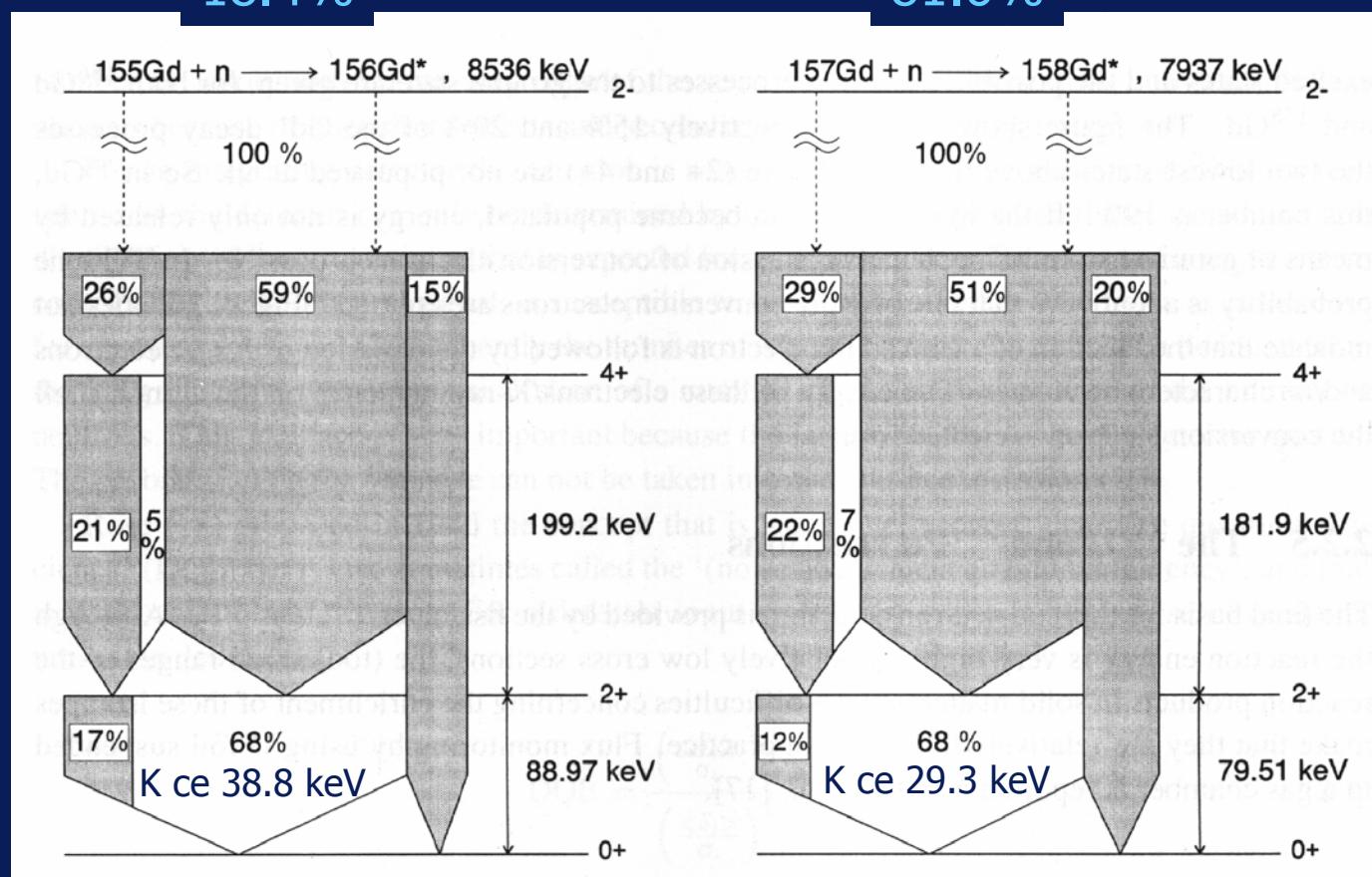


Gd based neutron scintillators

	av. em.wavel nm	X-ray LY ph/MeV	decay ns	en. res. FWHM(%) 662 keV	Dens. ρ g/cc	ρZ^4 10^6
Gd ₂ O ₂ S:Pr (UFC)	510	50,000	3×10^3		7.3	103
RbGd ₂ Br ₇ :Ce	420	54,000 (γ)	43 + 400	4.1	4.8	31
Li ₆ Gd(BO ₃) ₃ :Ce	400	14,000 (γ) ${}^6\text{Li}:50,000 (\text{n})$	200 + 800		3.5	

Inorganic Neutron Scintillators

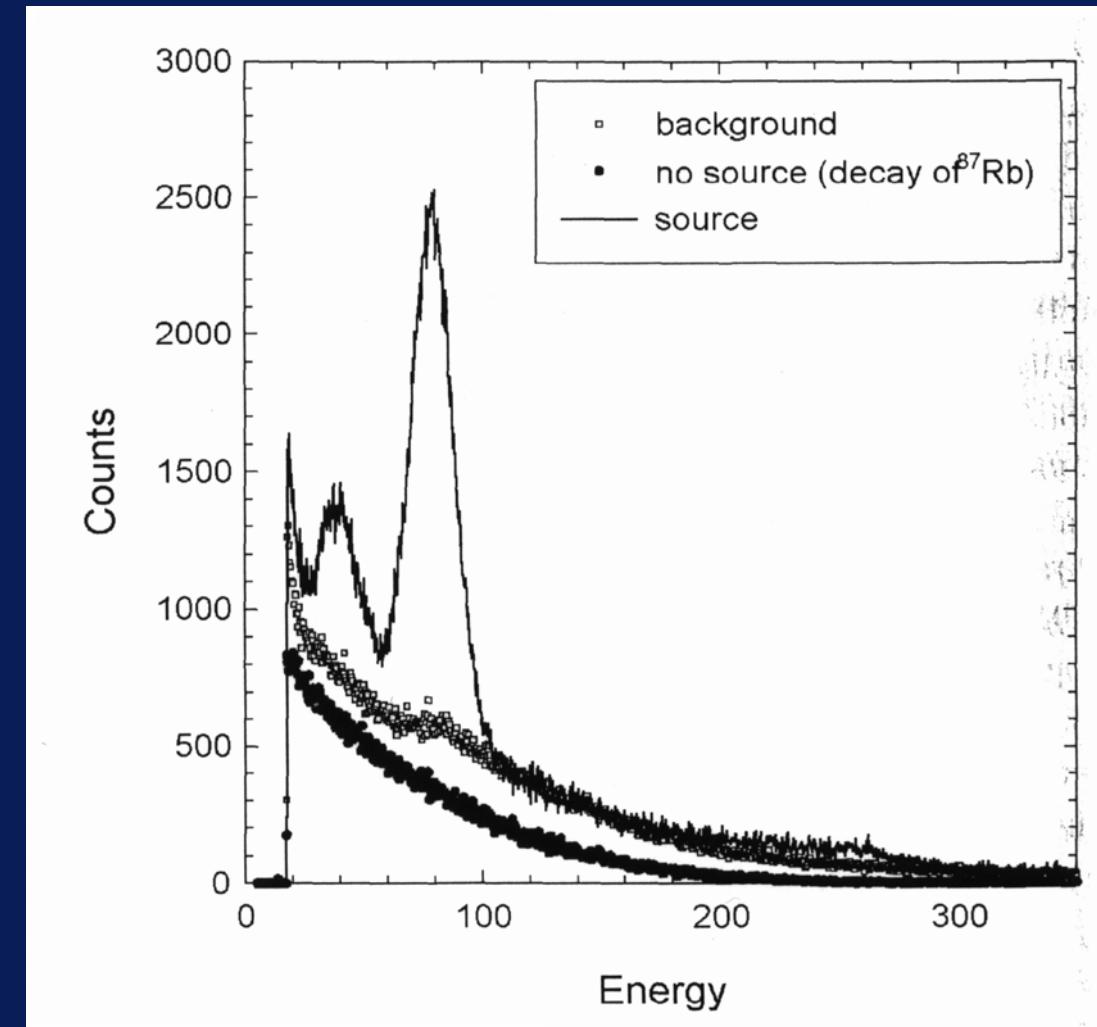
neutron capture in Gd isotopes 155 & 157



$K\text{ BE} =$	50.2 keV
$K\alpha \sim$	42.7 keV
$K\beta$	48.7 keV
ω_K	= 0.934

Inorganic Neutron Scintillators

Rb^{nat}Gd₂Br₇
+ PMT



Inorganic Neutron Scintillators

Gd based neutron scintillators & Si

	LY ph/MeV	LY ph/30keV	#e-h @50%QE in Si	$2/\mu_n$ @1.8 Å mm	$R_{el200keV}$ mm	$\frac{1/\mu}{Gd\ Kx}$ 80 keV mm	ρZ^4 10^6
Gd ₂ O ₂ S:Pr	50,000	1,500	750	0.02	0.06	0.33	0.6
RbGd ₂ Br ₇ :Ce	54,000	1,600	800 (~3kev in Si)	0.08	0.09		31
Li ₆ Gd (BO ₃) ₃ :Ce Si	14,000	400	200	0.08	0.12 0.16		

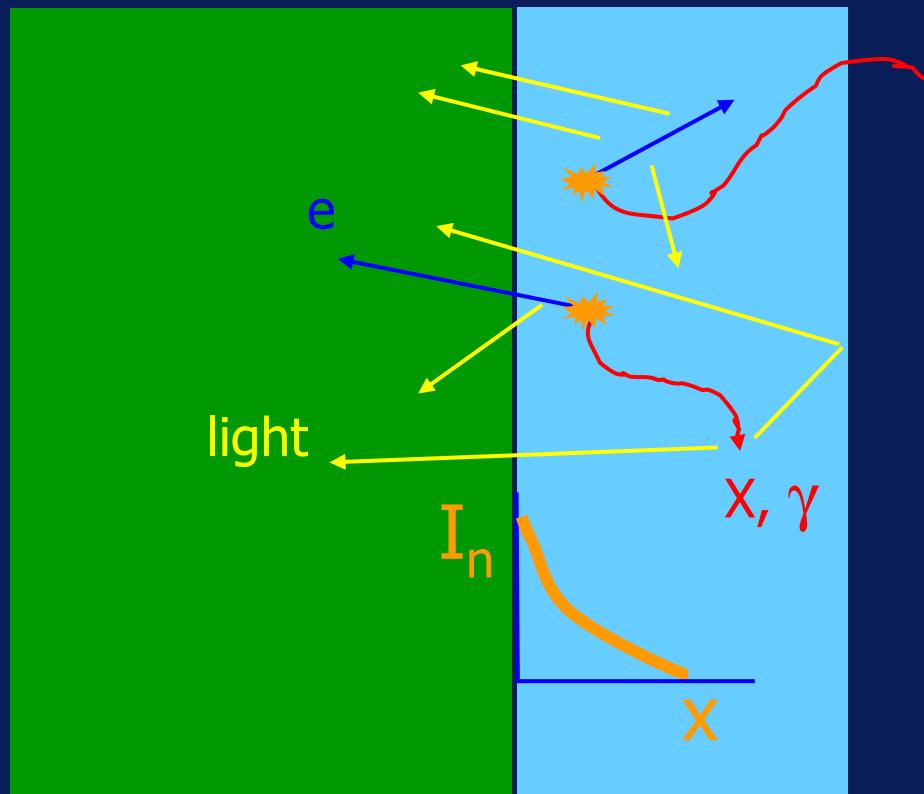


lower level in Si at ~ 500 eV

Inorganic Neutron Scintillators

Geometry

Silicon pos sens light sensor Inorganic scintillator



$\geq 300 \mu\text{m}$

$\sim 200 \mu\text{m}$

No need of
optimisation
neutron absorption
electron escape

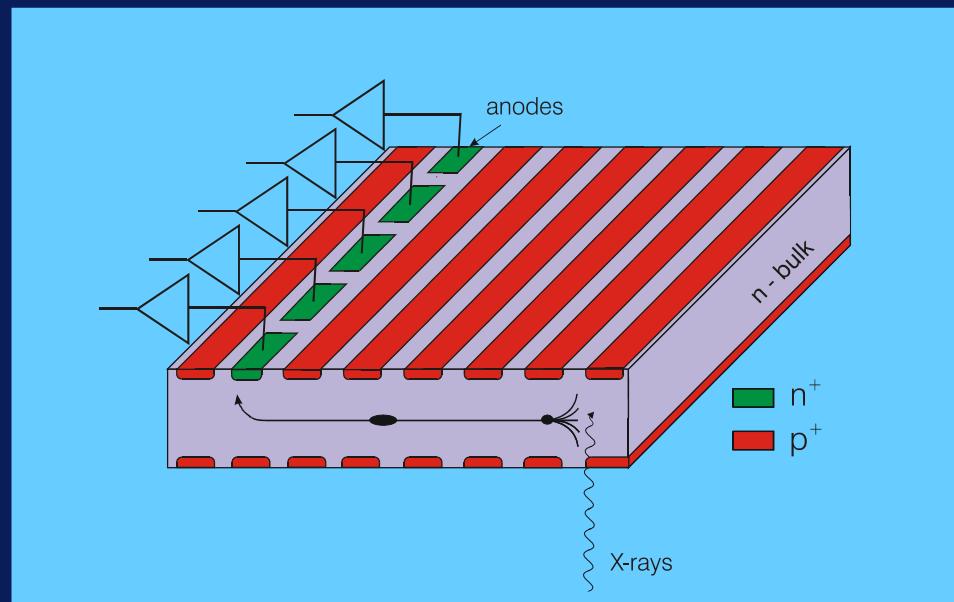
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Light Sensor:

Multi-anode linear Silicon Drift Detector

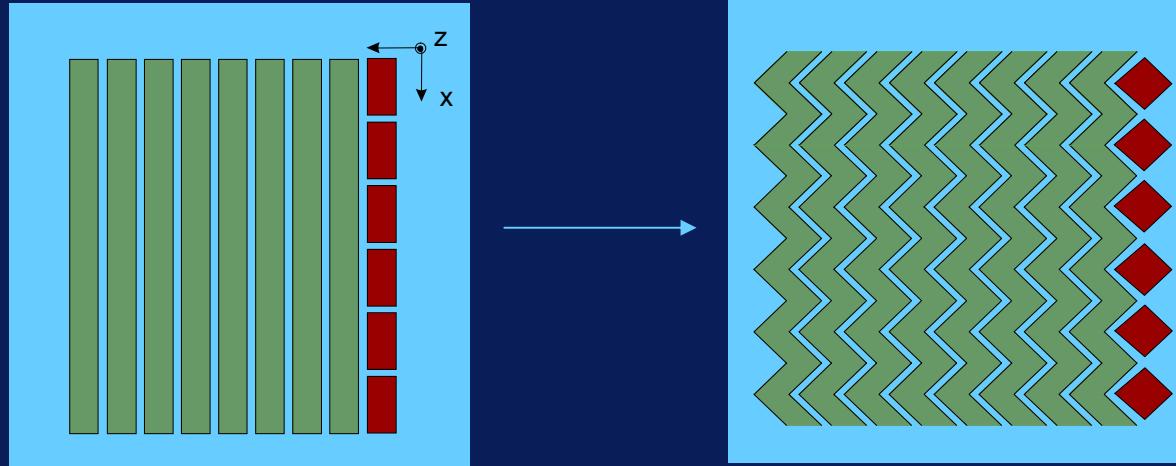
1D

- ideal configuration
- anode pitch determines the position resolution
- low noise features

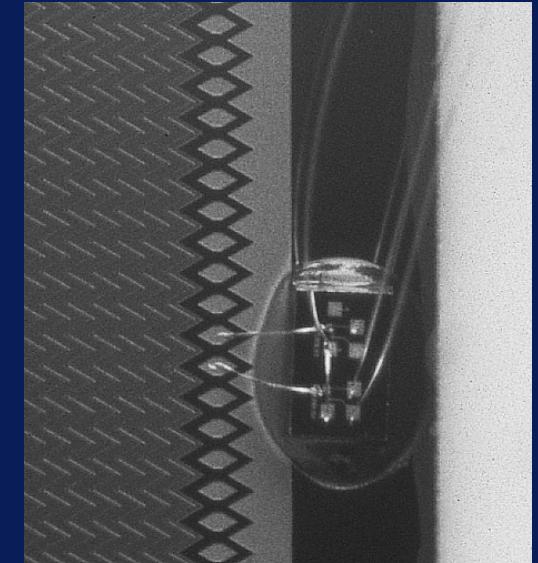
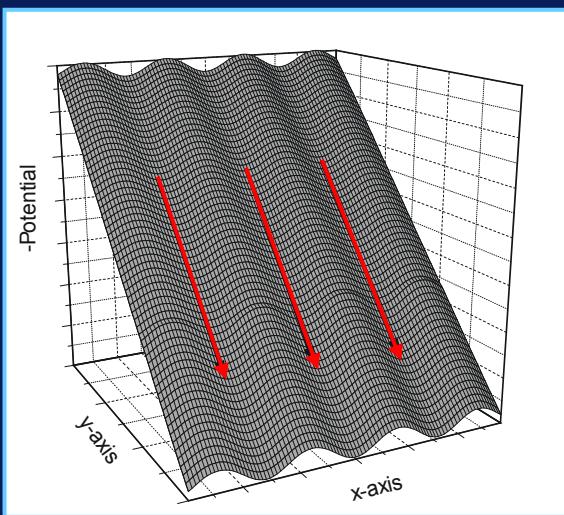
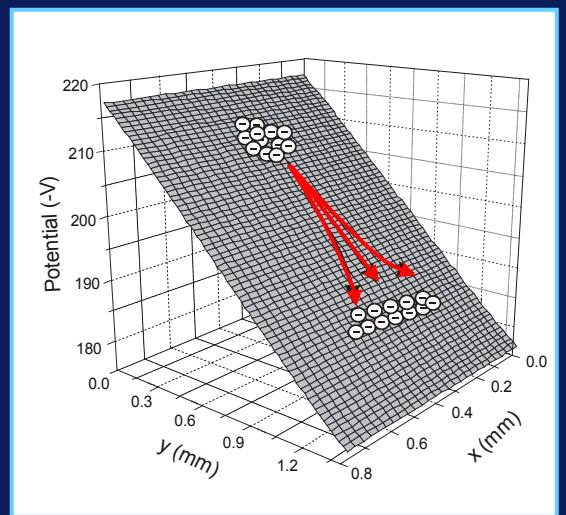


Inorganic Neutron Scintillators

■ Multi-anode Sawtooth SDD



- Sawtooth shaped p^+ strips induce potential gutters
- position resolution $\sim 250 \mu\text{m}$

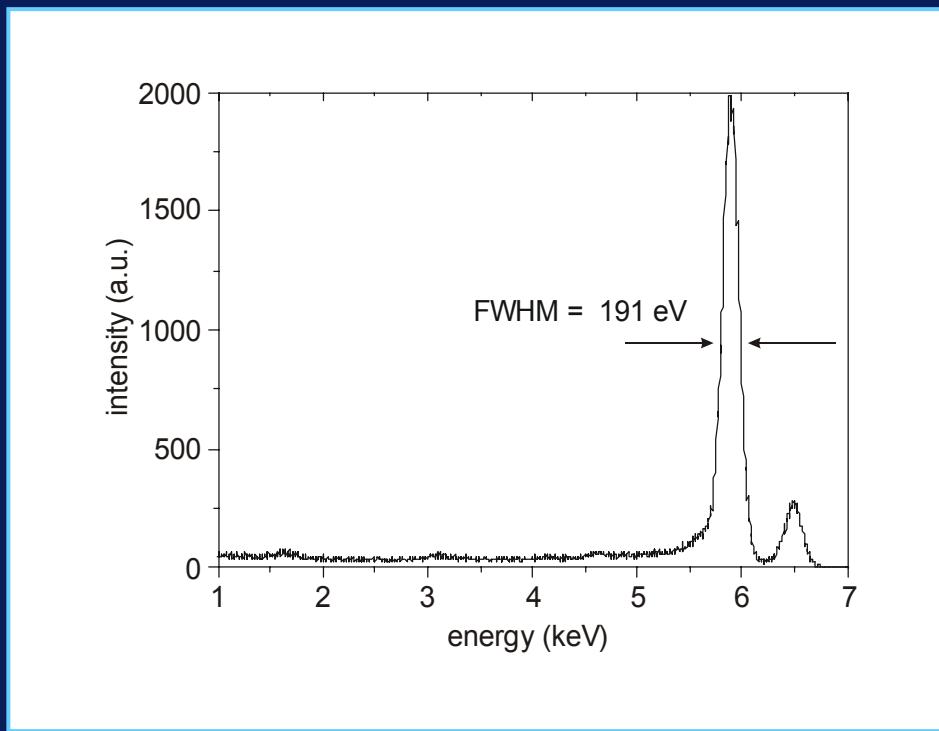


Inorganic Neutron Scintillators



MSSDD: X-ray spectroscopy

- large MSSDD fabricated on NTD wafers
- anode pitch of 250 micron



Results

- split events eliminated
- energy resolution of 190 eV at -60°C
- energy resolution of 350 eV at RT

Inorganic Neutron Scintillators



Bad news

Poor time information due to drifttime at microsecond level
However more hits per 250 micron channel can be handled

2D solution



Neutron arrival time +
start for drift time measurement

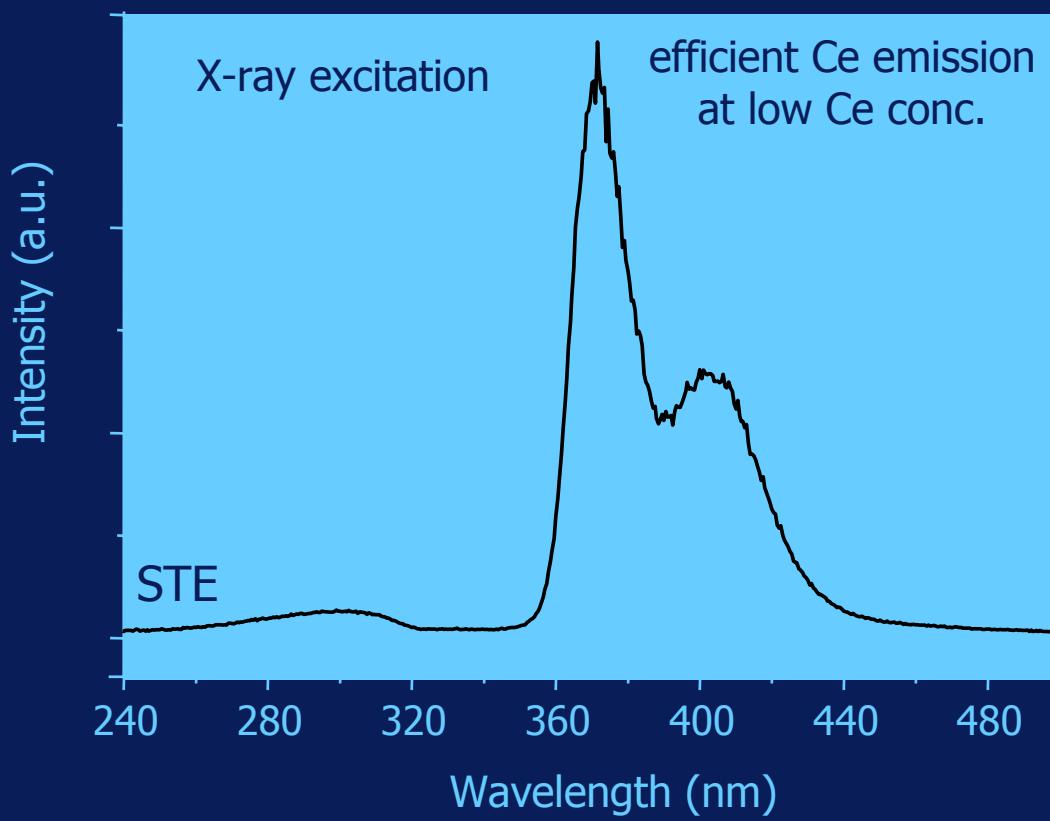
limited rate, depending on segmentation

“High” gamma-ray sensitivity

Inorganic Neutron Scintillators

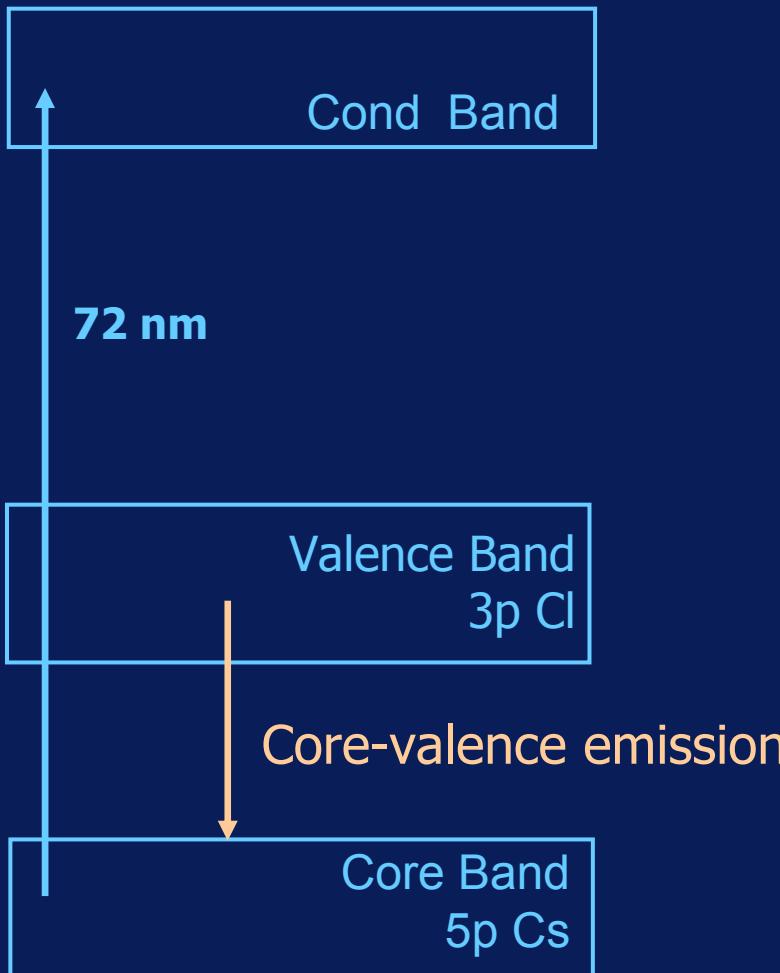
■

	av. em.wavel nm	X-ray LY ph/MeV	decay ns	energy. res. FWHM (%) 662 keV	dens. g/cc
$\text{Cs}_2\text{LiYCl}_6:0.1\%\text{Ce}$	380 255-470	33,000 weak	30 + slow 2.7	9	3.1



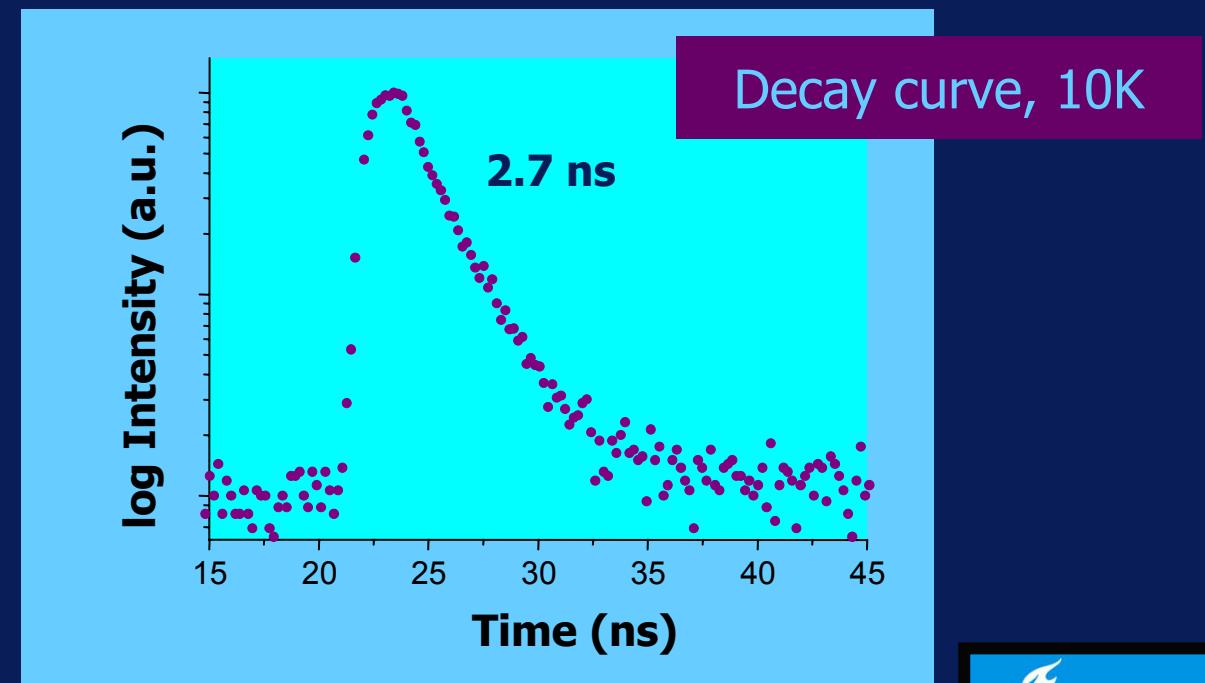
Inorganic Neutron Scintillators

■
 $\text{Cs}_2\text{LiYCl}_6:0.1\%\text{Ce}$



Core-valence luminescence

- Very weak intensity ($\sim 1000 \text{ ph/MeV}$)
- Broad (between 255 nm and 470nm)
- Excitation band at 72 nm



Inorganic Neutron Scintillators



$\text{Cs}_2\text{LiYCl}_6:0.1\%\text{Ce}$

Core-valence luminescence

Analogous neutron-gamma discrimination possible
as in $\text{LiBaF}_3:\text{Ce}$

Increase CVL?



Study at Ce conc. between 0 and 0.1%

(in the past looked at $\geq 0.5\%$)

Inorganic Neutron Scintillators

Conclusions

$^6\text{LiF}/\text{ZnS}:Ag$

well developed at ISIS
WLS fibre technique mature

limitation: opaque
efficiency 20 - 50%

GS20 ^6Li glass

WLS fibre
gamma camera

less light
efficiency 80%

$^6\text{Li}_6^{158}\text{Gd}(\text{BO}_3)_3:\text{Ce}^{3+}$

fibre readout
silicon well development

disadvantage:
depletion $^{155,157}\text{Gd}$

Gd scintillators

onto silicon - development

more efficient than
Gd foil converter
gamma sensitive

$\text{Cs}_2\text{LiYCl}_6:0.1\%\text{Ce}$

needs development

gamma ray suppression